eRD102 – dRICH

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The dual-radiator Ring Imaging Cherenkov (dRICH) detector is designed to provide continuous full hadron identification ($\pi/K/p$ separation better than 3σ apart) from ~ 3 GeV/c to ~ 60 GeV/c in the ion-side end cap of the EIC detector. It also offers a remarkable electron and positron identification from a few hundred MeV/c up to about 15 GeV/c. dRICH has been identified as reference detector for particle ID in the hadron endcap during the Yellow Report initiative.

The main technical goals for FY21 have been preparation of the basic version of the dRICH prototype, first test-beam, initial adaptation of the dRICH design to the EIC emerging detectors. The dRICH prototype is in advance construction phase, with the aim to be ready for the test-beams scheduled at CERN in fall 2021. A first test-beam (September '21) at the H6 beam line of SPS will use mesons with momenta between 40 GeV/c and 120 GeV/c to cover the high-momentum spectrum of the EIC hadron end-cap and study basic imaging performance for saturated rings (maximum Cherenkov cone aperture and photon yield). A second test-beam (October '21) at the T10 beam line of PS will use mesons with momenta below 15 GeV/c to investigate the transient region between the two radiator regimes. The tests are organized in synergy with ALICE and will have, as complementary targets, the study of the single-photon response of SiPM coupled to the ALCOR readout electronics, and the comparative use of Russian and Japanese aerogel. The goal of these initial test-beams is to perform a commissioning of the dRICH prototype and to define what has to be improved to reach the design performance. During the test-beam, the functionality of all the ancillary systems (tracking, trigger and timing, cooling, gas and vacuum, readout) should be validated.

R&D plan for FY22 and FY23-24 preview: The main technical goals of FY22 are the completion of a test-beam setup (prototype, readout, tracking, services) able to demonstrate dRICH performance, validate the dual-radiator approach and support simulations, and the study of dRICH integration into the EIC detector. FY23/FY24 R&D will be targeted to the definition of technical specifications to meet EIC requirements, matching to EIC-driven (developed by other EIC R&D) photosensors and readout electronics, and validation of cost-effective component technologies to mitigate the construction risk.

Prototype: During FY22 and following years the prototype will be upgraded to reach the full functionality. The first version of the prototype and the 2021 test-beam campaign concentrate on the proof-of-principle of the dual radiator imaging and irradiated SiPM usage. The initial realization of the prototype, tracking and gas system will be not sufficient to fully characterize the performance of all the components and reach complete optimization. To reach these goals, the dRICH prototype needs to be complemented with improved systems before new test-beam campaigns. The foreseen improvements concentrate on the most delicate elements. Following the first test-beam outcomes, the detector boxes will be revisited to optimize cooling plates and sensor geometry; the mirror system will be complemented with remote controlled step-motors, to allow proper alignment while the prototype is in operation taking beam; a greenhouse gas recovery system will be realized to allow safe operations and relax restrictions due to environmental regulations. For most of the components, a suitable and commercially available technology already exists as demonstrated by the developments pursued for the CLAS12 RICH: *e.g.*, customized aerogel of large area and high-clarity, use of composite materials for light mirrors of high optical quality, and stiff support structure of low density. However performance optimization, technical specification and risk mitigation require (as explained below) the adaptation of the prototype to different components to validate alternate qualified producers, optimize performance and pursue cost reduction. Examples are magnetic field tolerant photo-sensors and relative readout electronics, gas and aerogel radiators and their UV filtering septa, light mirrors. Financial support from INFN is expected to support part of these upgrades but a contribution from EIC project is essential for the prototype evolution and test-beam organization (50 k$ the first year, 20 k$ the following years).

Radiators: there are currently very few manufacturers of optical quality aerogel and even less with large production capability. Russian aerogel is basically an handcrafted product. Customization is possible towards world-leading performance in transparency and size, but the material is hydrophilic and requires special treatment. Mass production is possible but the production efficiency typically varies with time. Chiba University developed aerogel of excellent quality for the BELLE-II experiment and is now organizing a production facility called Aerogel Factory as spin-off. The quality and mass production capability need to be validated (the production for BELLE-II was done at the Japanese Fine Ceramic Company and reported issues for the largest refractive index). In USA, ASPEN company has pursued development programs for optical aerogel reaching decent transparencies at low refractive index. More recently, they collaborate with CUA to improve stiffness of very-low refractive-index aerogel. Funds are required (20 k$/yr) to acquire samples from this companies to assess the current status-of-the-art and initiate a customization program toward dRICH needs. Aerogel and gas refractive indexes need optimisation for photon yield, resolution and momentum coverage. Funds are requested (20 k$ in three years) to support the use of fluorocarbon gases C_2F_6, and alternatives, in conjunction with properly associated aerogel. Given the LHCb experience that reported a long-term degradation of the aerogel when immersed in fluorocarbon gas, a septum between aerogel and gas radiator is recommended. Such a window could act as a wavelength filter to suppress the UV light component that mainly undergoes Rayleigh scattering in aerogel. A similar window may be needed to separate the gas volume from the active area (sensor and electronics). For the initial dRICH beam-tests a commercial 3 mm acrylic sheet will be used to study the prototype optical performance. In FY22 a study of the radiation tolerance of the septum material will be initiated. Funds are requested (20 k$ in three years) to acquire the relevant samples (acrylic and quartz).

Photosensor and Electronics: In order to meet the EIC specifications a critical element, common to other EIC PID detectors, is a proper choice of the photosensor, that should preserve single-photon detection capability inside a strong magnetic field. The dRICH focusing system is designed to keep the detector outside the EIC spectrometer acceptance, in a volume with reduced requests in terms of material budget and radiation levels. This feature makes dRICH a natural candidate for the exploitation of magnetic-field tolerant SiPMs. It is expected that the optimized solution will be developed by the end of FY23 within the Photosensor and Radiation-Hard SiPM programs in conjunction with the electronics/ASIC program. Nevertheless, any realistic study of the dRICH performance relies on the availability of a suitable instrumented area: at least $10 \times 10\,\mathrm{cm}^2$ with less than 3 mm pixelization and sub-nanosecond time resolution. To be compatible with SiPM and support streaming readout tests, such electronics should also cope with high rates, up to 0.5 MHz per channel. The reference sensors (Hamamatsu H13700) and readout electronics (MAROC3) derived from the generic R&D program could be used in the initial dRICH test-beams (assuming to solve the sharing conflict with mRICH), but can not probe such EIC-driven performance. In FY22, a realistic SiPM active plane and readout will be realized to meet the above basic specifications. The SiPM choice will be based on the initial survey and irradiation campaign performed in FY21. The readout will be based on the ALCOR chip (a ToT discriminating architecture) and ARCADIA DAQ being developed at INFN. Their initial adaptation to the dRICH needs is assumed to be an INFN in-kind contribution. Funds are requested (40 k$ the first year, 20 k$/yr the following year) for acquiring status-of-the-art SiPMs and realizing the relative front-end boards with a baseline cooling integration.

Mirror: Being inside the EIC detector forward acceptance, the dRICH spherical mirrors should be light. Large area mirrors of optical quality compatible with RICH applications can be reliably produced at Composite Mirror Applications in Tucson, AZ, USA. CMA mirrors are made by two thin layers and a honeycomb core of carbon fiber reinforced polymer (CFRP) and achieve an areal density lower than 5 kg/m^2 and shaping accuracy better than 0.2 mrad. This company offers wide experience (HERMES, AMS, LHCb, CLAS12) and continuous improvements, but is the only one validated so far. Alternatives like the composite mirror R&D program ongoing in Chile (connected with ATLAS) and the glass-skin technology developed in Italy (for terrestrial telescopes) can only be pursued on a longer time scale.

In mirrors made of composite substrate, the surface roughness depends on the quality of the mold and stringent characteristics have to be imposed to obtain the needed roughness of 1-2 nm r.m.s and the sub-mrad surface accuracy. The innovative mold technology that CMA has developed is cost-effective for large mirror sizes but need validation for EIC needs. Quality, homogeneity and wavelength range of the reflective layer deposition is critical in large surface mirrors and its optimization requires the production and characterization of real-size mirror demonstrators. Most likely, a process of iterations with feedback from the dRICH team to the manufactures will be necessary. To pursue these targeted R&D dedicated funds would be required in FY23 and FY24 (30 k$/yr).

Engineering: The dRICH structure is divided in three main pieces. The aerogel volume, the gas volume and the photosensor boxes. The detector boxes, being outside acceptance, could be relatively massive to provide support for sensor, electronics, integrate services and cooling. Aerogel requires a support layer and an insulation window. Mirrors require a support with an integrated alignment system. While working at atmospheric pressure, the gas volume and supports could be realized by a skeleton of light CFRP ribs connected by tedlar foils (aka CLAS12 RICH). All these structures should be designed to comply with EIC detectors needs. Fluorocarbon gases are ideal radiators because at atmospheric pressure and room temperature they exhibit high density, corresponding to high refractive index, and low chromatic dispersion in the visible range, resulting in high accuracy. However, for such greenhouse gases, the market availability is subject to environmental regulations and a significant future price increase or shortage can not be excluded. When pressurized, noble gas density increases and they can mimic fluorocarbons very accurately: Argon at 2-2.5 bar absolute pressure can match EIC needs. Provided that mirrors and aerogel are fixed to a rigid internal structure, some deformation of the entrance and exit window are compatible with dRICH operation and the material budget is essentially driven by safety regulations. An initial engineering study will be pursued at INFN but would require a collaboration with BNL engineers to comply with the safety regulations. Funds are requested for technical support (30 k$ in three years).

Simulation and Integration: The dRICH concept can be adapted to different detector geometry and optimized in conjunction with other PID detectors. This can be primarily done with Monte Carlo simulations and CAD models, properly evolved following the prototype outcomes. Dedicated manpower is already working at DUKE and INFN but requires support to be able to continue the study.

Manpower: High-level expertise is available among the collaborating units covering all the aspects described above. INFN could count on 8 researchers (about 0.1 FTE each), several technicians and local infrastructures. DUKE on 2 researchers (about 0.1 FTE each). EIC funds would be crucial to co-fund young researcher positions and ensure dedicated manpower with long-term perspective. Three half post-doc positions are requested for a total of 100 k$/yr.

Milestones: Assessment of the basic prototype performance based on the 2021 test beams (March 22); Realization of a suitable photon detection plane for the dRICH prototype (June 22); Adaptation of the dRICH design to the selected EIC detector (September 22). The estimated timeline is subject to funds availability.

Funding profile: The dRICH project could count on a significant INFN in-kind contribution in infrastructures and expertise plus about 30 k$/yr covering the basic development, but relies on EIC project funds to mitigate the technological risk. Dedicated personnel can only be co-funded at this stage of the project. Continued financial support from the EIC project R&D program of the dRICH postdocs and their work on software as well as the dRICH prototype is crucial. The proposed funding profile and FY22 split is outlined in Table 1 and Table 2, respectively.

	prototype	radiators	mirror	detector	personnel	technical	travel	total
FY22	30	30	0	40	100	10	10	220
FY23	10	20	30	10	100	10	10	190
FY24	0	20	30	0	60	10	10	130

Table 1: Proposed EIC project funding profile in k$ (the assumed 30 k$/yr of INFN in-kind contribution is in addition). Personnel funds request takes into account hardware and software needs.

	prototype	radiators	mirror	detector	personnel	technical	travel	total
INFN	30	30	0	40	60		5	165
DUKE					40		5	45
BNL						10		10

Table 2: Proposed FY22 project funding split in k$. It is assumed the prototype evolution is concentrated in EU due to COVID restrictions (the assumed 30 k$ INFN in-kind contribution is in addition).